METHOD FOR PROVIDING A CONTROLLED INJECTION RATE AND INJECTION PRESSURE IN A FUEL INJECTOR ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. application Serial No. 09/245,106, filed January 29, 1999, entitled "Method and Apparatus for Providing a Controlled Injection Rate and Injection Pressure in a Fuel Injector Assembly."

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to a method for controlling injection rate and injection pressure in an electromagnetic fuel injector. More specifically, the invention relates to a method for controlling injection rate and injection pressure by varying current to a solenoid-actuated control valve to improve the operational characteristics of the fuel injector.

2. Background Art

Fuel injector assemblies are employed in internal combustion engines for delivering a predetermined, metered mixture of fuel and air to the combustion chamber at preselected intervals. In the case of compression ignition engines and diesel engines, the fuel/air mixture is delivered at relatively high pressures. Presently, conventional injectors deliver this mixture at pressures as high as 32,000 psi. These fairly high pressures require considerable engineering attention to ensure the structural integrity of the injector, good sealing properties, and the effective atomization of the fuel within the combustion chamber. However, increasing demands for greater fuel economy, cleaner burning, fewer emissions and NO_x control have placed, and will continue to place, even higher demands on the

engine's fuel delivery system, including increasing the fuel pressure within the injector.

Fuel injectors presently employed in the related art typically include a high pressure fuel passage, which extends between a solenoid-actuated control valve and the plunger cylinder in the injector body. Fuel at relatively low pressure is supplied to the control valve, which then meters the delivery of the fuel at very high pressures and at predetermined intervals through the high pressure fuel passage to the plunger cylinder. The fuel ultimately exits the injector through a fuel nozzle.

The solenoid-actuated control valve is supported in a stepped bore which typically extends through a side body of the injector. The stepped bore defines a supply chamber and a valve bore. The valve bore receives a valve stem of the associated control valve. The valve bore may terminate in a chamfered valve seat. Similarly, the valve stem may terminate in a head that seats against the valve seat under the force generated by the solenoid. The head is configured to mate closely with the valve seat. At least a portion of the valve stem is subject to the high pressure generated in a valve opening direction during an injection cycle. Accordingly, the solenoid must generate sufficient force in the valve closing direction to overcome such pressure. These forces are borne by the valve seat through the head of the control valve.

While the design and operation of fuel injections have continued to progress, there remains a constant need to improve fuel economy and reduce emissions while at the same time reducing engine noise induced from the operation of the fuel injector.

SUMMARY OF THE INVENTION

The invention results in improvements in the design and operation of fuel injectors of the related art. More specifically, the invention includes a method for controlling an electromagnetic fuel injector assembly for an internal combustion engine. The fuel injector assembly includes an injector body having a control valve

in fluid communication with a source of fuel for metering predetermined quantities of fuel to a nozzle assembly. The control valve is supported within a valve bore in the injector body and includes a solenoid connected to a source of electrical current and a valve member operatively connected to the solenoid and subject to the pressures developed in the injector for moving the valve member against a biasing force between open and closed positions. The valve bore includes a relieved portion. The solenoid responds to control signals developed by an electronic processor controlled by software using an algorithm with input variables determined by engine operating conditions. A regulated current for the solenoid from a source of electrical current is developed at preselected times during an injection event to slightly unseat the valve in response to forces acting on the valve member in the valve opening direction to regulate the injection pressure and the injection rate of the fuel injector assembly. The valve member or the valve bore may include a relieved portion, which results in a reduced surface area contact between the valve head and the valve seat.

The method includes the step of providing a first level of regulated current to the solenoid actuator to cause the valve to partially seal the high pressure nozzle assembly passage from a fluid pressure spill passage, thereby allowing the regulated pressure in the nozzle assembly to rise to an initial injection pressure. A reduced level of regulated current then reduces the sealing force of the valve to create a reduced initial injection pressure. An increased level of regulated current greater than the first level then allows the regulated pressure to rise to a peak value and create a peak injection rate controlled period near the end of the injection event. That is followed by controlling the current to effect a controlled decrease in injection pressure and injection rate at the end of the injection event.

One advantage of the present invention is that the method controls the injection rate and injection pressure of the electromagnetic fuel injector assembly for calibrated injection times using software to control the levels of current directed to the solenoid during calibrated pressure regulation and to control the duration of the regulation.

Another advantage of the present invention is that by controlling the initial injection rate in diesel engines, the initial combustion rates may be reduced to lower engine noise and reduce NO_x emissions.

Still another advantage of the present invention is that by regulating the maximum injection pressure, the cam and plunger associated with the injector assembly may be sized to provide high injection pressures at low speed and load thereby improving fuel economy and reducing soot formation while, at the same time, preventing excessive structural loads at higher speeds and loads through the pressure regulation function.

Still another advantage of the present invention is that the depressurization rate of the fuel injector may be controlled. More specifically, reducing the depressurization rate or spill rate reduces the mechanically induced engine noise caused by the rapid unloading of the drive system. This feature is applied by the present invention by lowering the current to the solenoid at the end of the injection event thereby slightly unseating the valve member prior to fully terminating the current to the solenoid. By regulating the current to the solenoid at the end of the injection event, the acceleration forces acting on the valve member in the valve opening direction may be reduced resulting in a reduced depressurization rate.

BRIEF DESCRIPTION OF THE DRAWINGS

Other advantages of the invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIGURE 1 is a partial cross-sectional side view of an electromagnetic fuel injector;

FIGURE 2a is a partial cross-sectional side view of a conventional valve member of a solenoid-actuated control valve for an electromagnetic fuel injector;

FIGURE 2b is an enlarged, partial cross-sectional side view of the valve member illustrated in Figure 2a;

FIGURE 2c is a partial cross-sectional side view of a valve member of a solenoid-actuated control valve for the present invention illustrating a relieved portion in the valve bore thereof;

FIGURE 2d is an enlarged, partial cross-sectional side view of the valve member of Figure 2c;

FIGURE 2e is a partial cross-sectional side view of a valve member of a solenoid-actuated control valve of the present invention illustrating the relieved portion on the head of the valve member;

FIGURE 2f is an enlarged, partial cross-sectional side view of the valve member of Figure 2d; and

FIGURE 3 is a graphical representation of the movement of the control valve as a function of solenoid current with reference to the injection pressure over time.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figure 1, there is generally shown at 10 an electromagnetic fuel injector assembly of the type commonly employed in injectors with an internal combustion engine wherein fuel is injected into a plurality of cylinders where it is combusted to generate power to rotate a crankshaft. More specifically, fuel injector assembly 10 shown in Figure 1 has an electromagnetically-actuated, pressure-balanced control valve incorporated therein to control fuel

discharge from the injector nozzle portion of assembly 10 into a cylinder of the engine (not shown) in a manner to be described. As illustrated in this figure, the electromagnetic fuel injector assembly 10 includes an injector body 12, which has a vertical main body portion 14 and a side body portion 16. The main body portion 14 includes a stepped, cylindrical bore 20 therethrough. The stepped, cylindrical bore 20 includes a pump cylinder 22, which slidably receives a pump plunger 24. In addition, the stepped, cylindrical bore 20 includes an upper wall 26 of larger internal diameter to slidably receive a plunger actuator follower 28. The plunger actuator follower 28 extends out one end of the main body 14 whereby it and the pump plunger 24 connected thereto are adapted to be reciprocated by an engine driven cam or rocker as known in the art. A stop pin (not shown) extends through an upper portion of the main injector body portion 14 into an axial groove in the plunger actuator follower 28 to limit upward travel of the follower under the bias of a plunger return spring 34.

A nut, generally indicated at 36, is threaded to the lower end of the main body portion 14 and forms an extension thereof. The nut 36 has an opening 38 at its lower end through which extends the lower end of a combined injector valve body or nozzle assembly, generally indicated at 40. The nozzle assembly 40 includes a spray tip 42. The nozzle assembly 40 may include a number of elements, which are well known in the art and which form no part of the present invention. Accordingly, the inner workings of the nozzle assembly 40 will not be described in detail here.

The delivery of fuel from a source such as a fuel tank to the nozzle assembly 40 is controlled by means of a solenoid-actuated, pressure-balanced valve, generally indicated at 44 in the side body portion 16. The side body portion 16 is provided with a stepped vertical valve bore, generally indicated at 46, which defines a supply chamber 48 and an intermediate or valve stem guide portion 50. The guide portion 50 of the valve bore 46 terminates in a valve seat 52. The valve seat 52 is chamfered so as to define an angle relative to the centerline of the valve bore 46. The valve 44 is received within the stepped vertical valve bore 46 and includes a valve member having valve stem 60 terminating in a head 54, which seats against

the valve seat 52. The stem 60 extends upward from the head 54. A closure cap 56 is mounted to the underside of the side body portion 16 and forms therewith a spill chamber 58.

The valve 44 is normally biased in a valve opening direction, downward with reference to Figure 1, by means of a coil spring 62, which loosely encircles the valve stem 60. One end of the spring 62 abuts against a washer-like spring retainer 64 encircling the valve stem 60. The other end of the spring 62 abuts against the lower face of a spring retainer 66. Movement of the valve 44 in the valve closing direction, upward with reference to Figure 1, is effected by means of a solenoid assembly, generally indicated at 68. The solenoid assembly 68 includes an armature 70 having a stem 72 depending centrally from its head. The armature 70 is secured to the valve 44.

As commonly known in the art, the solenoid assembly 68 may further include a stator assembly having an inverted cup-shaped solenoid case 74. A coil bobbin supporting a wound solenoid coil and a segmented multi-piece pole piece are typically supported within the solenoid case 74. The solenoid coil is connected through electrical connectors 76 to a suitable source of electrical power via a fuel injection electronic control circuit (not shown) under the control of a software algorithm using input variables that are determined by engine operating conditions. Thus, the solenoid coil can be energized as a function of engine operating conditions, as will be described in greater detail below.

A high pressure fuel passage, generally indicated at 78, provides fluid communication between the control valve 44 and the fuel nozzle assembly 40. As shown in Figure 1, the fuel passage 78 is formed by drilling a hole from one side of the side body portion 16 of the injector body 12 and between control valve 44 and the stepped cylindrical bore 20. In this way, the fuel passage 78 defines a delivery portion 80 extending between the control valve 44 and the stepped cylindrical bore 20 and a portion 82 extending between the valve stem guide portion 50 in the control valve 44 and the side body portion 16. A plug 84 seals the open end of the portion 82 of the high pressure fuel passage 78.

As illustrated in Figure 1, the valve member, including the valve stem 60 and at least a portion of the head 54, are subject to high pressure via the delivery portion 80 of the fuel passage 78 developed by the injector. Thus, when energized, the solenoid assembly 68 moves the valve member toward the closed position against the biasing force of the spring 62 and the pressures acting on the valve member via the fuel passage 78.

Referring now to Figures 2a and 2b, a conventional valve member movably supported in the guide portion 50 of the valve bore 46 is disclosed. The head 54 of the valve member is held against the valve seat 52 and against forces acting on the valve in the valve opening direction by the solenoid assembly 68. However, as shown in Figures 2c and 2d, the guide stem portion 50 of the valve bore 46 may include a relieved portion 86, which is subject to the pressures developed in the injector to provide forces acting on the valve member in the valve opening direction. Alternatively, as shown in Figures 2e and 2f, the head 54 of the valve 44 may include a relieved portion 90, which results in reduced surface area contact between the head 54 and the valve seat 52. Either of the relieved portions 86 on the guide stem portion 50 of the valve bore 46 or the relieved portion 90 on the head 54 of the valve member may be employed to balance the control valve 44 in the following manner.

During any given injection event, the solenoid assembly 68 may be subject to reduced current from the source of electrical current at preselected times to slightly unseat the valve member in response to the forces acting on the valve member in the valve opening direction and, in this way, to regulate the injection pressure and injection rate of the fuel injector. More specifically, and referring now to the graphs of Figure 3, the movement of the control valve 44 as a function of the solenoid current is illustrated with reference to the injection pressure over time. As noted above, initiation of current at 92 supplied to the solenoid moves the control valve 44 in the valve closing direction as indicated at 94. The pressure in the injector begins to rise as shown at 96. Employing the method of the present invention, during the initiation of the injection pressure, the current to the solenoid may be reduced at 98 to slightly unseat the valve member represented at 100 thereby

controlling the rate of injection of the fuel and fuel pressure as indicated at 101. The current to the solenoid may then be increased again as indicated at 102 thus moving the valve member to its closed position as indicated at 104.

Thereafter, when the pressure in the injector approaches the peak injection pressure as indicated at 106, the level of current to the solenoid may be reduced as indicated at 108 to slightly unseat the valve member as indicated at 110 thereby regulating the maximum pressure in the injector. At the end of the injection cycle, the level of current to the solenoid may again be reduced as indicated at 112 to slowly unseat the valve assembly shown at 114 thereby controlling depressurization of the injector as indicated at 116. More specifically, the rate of depressurization at 116 is slowed when compared with the depressurization of conventional injectors shown in dotted lines at 118. Finally, once the injection event is completely over, the current to the solenoid is ended thereby moving the valve member to its open position under the influence of the spring 62 and any pressure existing in the fuel passage 78.

In this way, the injection rate and injection pressure in the electromagnetic fuel injector assembly may be controlled. The length of injection time and the level of current directed to the solenoid during the regulation modes determines the level of pressure regulation and the duration of the regulation. However, by increasing current to the solenoid at any time, valve sealing can be reestablished to resume traditional injection functions. Additionally, by controlling the initial injection rate in diesel engines, the initial combustion rates may be reduced to lower engine noise or reduce NO_x emissions. Furthermore, by regulating the maximum injection pressure, the cam and plunger associated with the injector assembly may be sized to provide high injection pressures at low speed and load thereby improving fuel economy and reducing soot formation while, at the same time, preventing excessive structural loads at higher speeds and loads through the pressure regulation function. Finally, the depressurization rate of the fuel injector may also be accurately controlled. More specifically, by reducing the depressurization rate or spill rate, the mechanically-induced engine noise caused by the rapid unloading of the drive system may be reduced. This feature is achieved

by the present invention through lowering the current to the solenoid at the end of the injection event thereby slightly unseating the valve member prior to fully terminating the current to the solenoid. By regulating the current to the solenoid at the end of the injection event, the accelerating forces acting on the valve member in the valve opening direction may be reduced resulting in reduced depressurization rates.

The invention has been described in an illustrative manner. It is to be understood that the terminology which has been used is intended to be in the nature of words of description rather than limitation.

Many modifications and variations of the invention, as well as equivalents thereof, are possible in light of the above teachings. Therefore, within the scope of the appended claims, the invention may be practiced other than as specifically described.